Long-Range Visibility Effects on Driver Braking Response Distance

Final Report

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*Graphic on this page from National Highway Traffic Safety Administration, http://www.nhtsa.dot.gov/cars/problems/studies/LTV/

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List of Acronyms

FHA	Federal Highway Administration
MIT	Massachusetts Institute of Technology
MPH	Miles per hour
PRT	Perception Reaction Time
SDL	Scenario Definition Language
STI	Systems Technology, Inc.

Abstract

This project hypothesizes that an increase in a driver's long-range vision capability of 200 feet will correspond to a 10% increase in that driver's braking response distance. The link between driver performance and long-range vision is thought to be one of the causes for an increase in accident rate as drivers enter old age and their vision degrades. However, prior to this project, very little previous work has been done to assess the relationship between vision capability and its impact on driver performance. At the Massachusetts Institute of Technology Age Lab Driving Simulator, thirty subjects between the ages of 18 and 30 were asked to respond to eight obstacles that appeared at 400, 600, 800 and 1000 feet down the roadway. The driver's braking response distance was extracted from the data collected and compared. This project concludes that for vision capabilities between 400 feet and 800 feet an increase of 200 feet does produce a 10% increase in braking response distance. There was no statistical difference in braking response for vision ranges between 800 and 1000 feet, suggesting that there is a threshold distance beyond which increasing vision range does not affect braking response distance.

1.0 Introduction

1.1 Project Motivation and Significance

According to the National Institute for Aging,[3] in twenty years, in one in five Americans will be older than 65 years, and will most likely be licensed to drive. As a group, the over-65 drivers have a higher crash rate than any other age group when amount of driving is considered a factor. One reason suggested for the discrepancy is poorer vision in older drivers. More research needs to be done to assess how the degradation of long-range vision affects the performance of a driver, and that driver's ability to react to a dangerous situation while driving.

This project will assess the role that visibility range plays in driver performance. Since the conclusion of this experiment is that there is a significant difference in driver performance as vision range degrades, it suggests that further research is needed to compensate for aging drivers' decreasing vision

1.2 Project Hypothesis

How a driver reacts to an obstacle in the distance has been little studied. One might expect that a driver will begin to brake at the same distance from an obstacle, regardless of how far away the obstacle was when it appeared in the driver's field of view. On the contrary, it may be possible that if a driver is aware of an obstacle in the distance, he/she will react to it sooner. It is with these questions in mind that the project hypothesis was proposed. Therefore, this project hypothesizes that an additional 200 feet in a driver's long-range vision increases the driver's braking response distance by 10%; braking response distance is the distance away from the obstacle the driver is when he/she begins to brake, and long-range vision refers to obstacles that are 400 feet or more in the distance. (See Section 4.2, Problem Definition, for a detailed explanation of terms.)

1.3 Overview of Previous Work

Several studies have been conducted to compare the reaction times of older and younger drivers to an unexpected event on the roadway. An "unexpected event" normally appears within only a few hundred feet from the driver. Most of these studies have found that there is a significant difference in the way older and younger drivers react to these unexpected obstacles. These experiments have been conducted in either a simulated environment, or on actual roadways.

However, there has been very little prior research done studying the effects that long-range vision has on a driver's braking response distance or breaking response time. Since decreased vision capability is an expected result of aging, one might expect that it would be difficult for an elderly person to perceive an obstacle on the road in the distance and react in enough time to avoid collision. There has been previous research done to study the effects that certain vision impairments common to the elderly have on their driving performance; for example cataracts, or glaucoma. Thus, it is necessary to study how drivers react when they are faced with obstacles that are anticipated in the distance. Please refer to Section 3.0, Literature Review, for more details about previous works.

1.4 Value to Drivers

This project will study the effects of degrading vision on driver performance by forcing drivers to brake in response to events that become visible for the first time at varying distances. For example, a driver will have to brake in order to avoid hitting a pedestrian that became visible for the first time 400 feet in the distance, than at 600 feet, then at 800 feet, and finally at 1000 feet. The distances before each object that the driver began to brake will be compared to see if the drivers are reacting earlier in the cases where they have more time to react, and at what point there is no longer a difference in reaction. This study will use younger drivers (18-30). If the results show that there is a concrete difference in performance, and that the results are reliable with a strong level of confidence, then MIT's Age Lab will pursue further testing with older drivers. The value to drivers, and in particular older drivers, is to more clearly define the role of long-range vision in the hopes of correcting or aiding those problematic factors that are contributing to the high crash rates among that age bracket.

2.0 Project Statement

2.1 Objective

Evaluate through simulations in the MIT Age Lab Driving Simulator:

a) Whether the addition of 200 feet in long range vision (1000 vs. 800 feet, 800 vs. 600 feet, or 600 vs. 400 feet) causes a significant difference in braking response distance for a driver, and

b) Whether the addition of 200 feet is enough to cause a 10% increase in a driver's braking response distance.

2.2 Success Criteria

Determine, with a confidence level of at least 90%, whether there is a 75% probability that a driver's braking response distance will be increased by 10% or more if the driver's long range vision capability is increased by 200 feet.

3.0 Literature Review

3.1 Problem Definition

Scialfa et al[4] attempted to determine if older adults had more difficulty than younger adults in judging either the distance or speed of approaching vehicles. The study reported that the elderly are far more likely to be involved in accidents that involve failure to heed signs, yield right of way, or turn safely. However, the study concedes that no research current at the time of its publication in 1997 have assessed the degree to which degrading vision has contributed to these types of accidents. It is just that question that motivates this project. Furthermore, the study pointed out that an estimated 90% of information used for driving is visual, and that correlations between visual measures and safe driving have proved to be higher among old drivers than young ones. This supports the intent of this experiment to measure the effects of degrading vision in younger drivers, and then if those effects prove significant, the MIT Age Lab will continue the research with older drivers.

3.2 Braking Response Time Studies

There have been several studies on the differences in breaking response times to unexpected events for different age groups. Lerner[2] received funding from the Federal Highway Administration (FHA) to test their currently used perception-reaction time (PRT) design value of 2.5 seconds. PRT refers to the time required to "perceive, interpret, decide, and initiate a response to some stimulus." This value is used for setting such parameters as the radii of highway curves and the length of time for traffic light color changes. The FHA was concerned that their currently used PRT value of 2.5 seconds was not enough reaction time for older, slower responding drivers.

Lerner's study involved 200 drivers from 3 different age groups, 20-40, 65-69, and 70+ years old. These drivers drove their own vehicles on a real stretch of highway. At some point in the trial, the drivers were instructed to driver beyond a barricaded section of highway, where the speed limit was 40 miles per hour (mph). After driving about 0.35 miles beyond the barricades, a large yellow barrel was released and rolled onto the roadway about 200 feet in front of the driver. Using an in-vehicle camera and pressure sensitive tape on the accelerator and brake pedals, the driver's performance was recorded. The study had to discard all but 56 subjects' data for reasons of incorrect behavior, inclement weather, and equipment failures. The study found that there was no difference in PRT for older or younger drivers and that virtually all drivers' PRT values was captured by the 2.5 second design value.

This study calculated the driver's PRT value by assuming the driver was driving at a speed of 40mph, creating an immeasurable amount of error in the actual PRT value for the driver. Thus, in the experiment carried out by the authors, braking response distance, rather than time, was measured as the key value of comparison between drivers. Using response distance will eliminate the error created by drivers approaching the obstacles at different speeds.

On the contrary, Broen and Chiang[1] found that there was a significant difference between older and younger drivers' response times. This study examined the effects that different pedal configurations had on braking response time to an unexpected event for 100 drivers of various ages. Each driver drove through a simulated suburban test environment in a driving simulator 21 times with different pedal configurations. The unexpected event, two pedestrians crossing the road, occurred at a random time during the experiment. Although this study explains in detail the several pedal configurations used in the experiment, the end result of their study was that pedal configuration did not significantly impact the drivers' response time. Age, however, did have a significant result on a driver's response times. Drivers in the 51+ age range responded, on average, 0.19 seconds slower than drivers in the 18-30 age group. Other parameters being compared, such as gender, shoe size, and driver height, had no effect on the driver's response.

This study was useful to this project because it established that using pedestrians as an obstacle in the simulator is a successful event for measuring a driver's response time. A pedestrian crossing the road is both a likely situation in a real-world driving situation and easy to program in the driving simulator. In addition, this study set the precedent that the authors of this project do not need to be concerned that the pedal locations in the driving simulator, different from ordinary vehicles, will have any effect on a driver's braking response.

3.3 Vision Effect Studies

As mentioned previously, there has been very little research done prior to this project that studies the effects of long-range vision on drivers. However, it is an issue of importance to the driving community, especially for older drivers. Recently at Queensland University in Australia, Wood[5] has led several involving the effects of vision and vision degradation in drivers. By using closed road circuit driving facilities at the Department of Transport in Brisbane, Wood and several of her research assistants have begun to assess the role that deterioration of vision due to aging and common eye diseases, like glaucoma, cataracts and macular degeneration, play in driver performance. Their preliminary studies have shown that visual impairment can significantly reduce driver performance. However the studies have shown that some older, impaired drivers do retain a high level of driving performance. These studies are aimed at developing better techniques to identify which elder or visually impaired drivers are driving risks.

From these studies at Queensland, it is important to note that there is still very much to be learned about how vision, especially long range vision, affects the way in which drivers react to situations on the road.

4.0 Description of Experiment

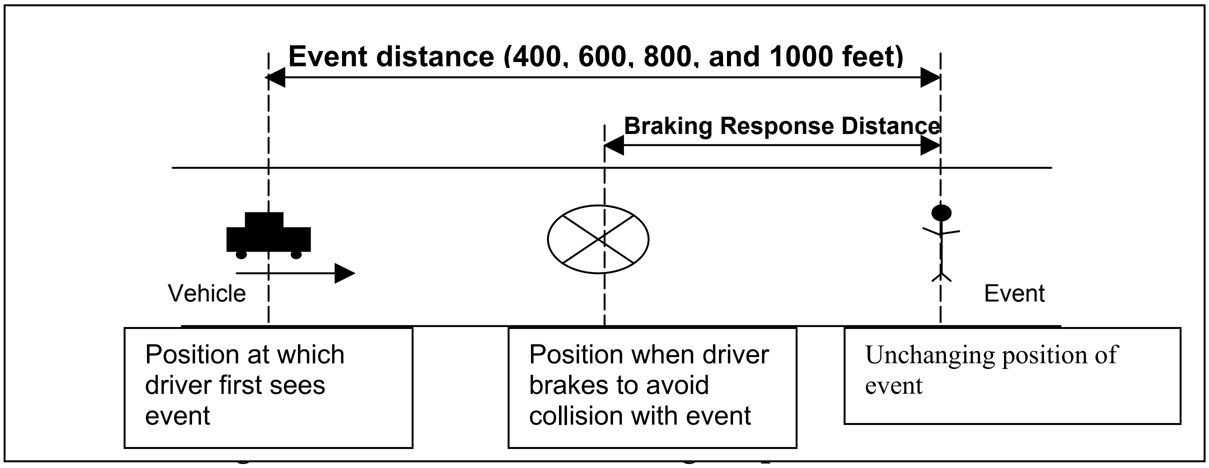
4.1 Experiment Overview

This project can be broken up into 5 main parts: defining the problem, designing the experiment, developing the necessary software, testing the subjects, and finally collecting the data in needed to assess the hypothesis.

The final definition of the problem was to have a scenario of eight events to correspond to a pedestrian crossing the road, and a parked car in the roadway, appearing at intervals of 200 feet between 400 feet and 1000 feet. Concurrently, the experiment design was formulated according to the method of Latin Squares, where there were eight possible test scenarios, of which each subject was assigned one. Each test had the eight vehicle and pedestrian events ordered differently to eliminate inter-event interaction. Next those scenarios had to be programmed to be displayed in the driving simulator. The actual subject testing took place at the MIT Age Lab Driving Simulator Lab. There, thirty subjects were given a pretest questionnaire, a practice scenario to drive, and then one of the eight test scenarios complete with the eight different events to which they needed to react. Finally the braking response of each of the drivers to the events was collected, and from that, the breaking response distance was extracted.

4.2 Problem Definition

The problem definition process started with deciding what information was necessary to access the hypothesis. A single metric was needed to compare a driver's responses to events occurring at differing distances down the road. The metric chosen was the distance from the object at which the driver began to brake in response to an event (Braking Response Distance). See Figure 4.1, Definition of Braking Response Distance, for a pictorial representation.



Each scenario consisted of two event types. The first event type is the pedestrian event. During this event a pedestrian appeared in the distance and crossed the road, so that it blocked the roadway ahead of the driver. The pedestrian appeared at distances of 400 feet from the car, 600 feet from the car, 800 feet from the car, and finally 1000 feet in front of the car. This produced 4 distinct pedestrian events. The second event type is the parked vehicle event. There was a parked vehicle obstructing the roadway in front of the driver. The vehicle also appeared at intervals of 200 feet from 400 feet to 1000 feet, producing a total of 4 distinct vehicle events. Between the vehicle and pedestrian events, there are 8 events to which the driver must respond by braking.

4.3 Experiment Design

The experiment design focuses on how the subjects were chosen and how the relevant tests were presented to them. The subjects ranged in age from 18-30 years. Although the project asked for volunteers between the ages 18-30 years, the average age of the test subjects only turned out to be 20 years. This is most likely due to the large number of undergraduate MIT students who were available for testing. Both males and females were tested equally in an effort to rule out effects due to gender. The younger drivers all had vision corrected to at least 20/20 at the time of the test. They were all in good health, and all had a valid drivers' license. This group was chosen since they in general do not posses the aliments such as slower reaction time, or degrading depth perception, generally associated with aging. Due to this fact, the driving performance could be more directly linked to the sole factor of long-range vision.

The second task was how to order the eight events in a test. The relevant questions were how to minimize the learning curve of the subjects and the effects of inter-event interaction. The method of Latin squares was used to randomize the order of the 8 events in a test. This method produced 8 different tests, each a different random permutation of the 8 events. There were far less females, than males, but all eight of the different tests were performed by at least one female, so that the possibility of gender effects was reduced. See Table 4.1, Method of Latin Squares, for a further description of the experiment design based on the method of Latin Squares.

Table 4.1 – Method of Latin Squares

S1	S2	S3	S4	S5	S6	S7	S8
1	2	3	4	5	6	7	8
6	7	8	1	2	3	4	5
3	4	5	6	7	8	1	2
5	6	7	8	1	2	3	4
7	8	1	2	3	4	5	6
2	3	4	5	6	7	8	1
4	5	6	7	8	1	2	3
8	1	2	3	4	5	6	7

S1-S8: Subject perform experiment in corresponding column

1-8: Events performed by the subject (Two at each of four distances)

4.4 Software Development

For the hypothesis to be evaluated by the chosen test subjects, two different software sections had to be developed: a configuration file that defined the dynamics of the simulator vehicle; and the actual program that defined and displayed the graphics for the test segments, and recorded the driver's performance. The language in which the software was written is called Scenario Definition Language (SDL), and is part of a professionally developed software program by Systems Technology, Inc. (STI) called STISIM. STISIM allows the programmer to develop simple, high-level code in a predefined scheme in either STISIM, or by using Microsoft Excel with Visual Basic Editor as the compiling tool. This software, in turn, plays the developed graphics on large screen driving display, while also controlling the dynamics of the vehicle, and monitoring the driver's performance (speed, braking, distance traveled, etc.).

4.4.1 Description of Vehicle Dynamics Configuration Software

The driving "shell," called so because the engine has been removed and replaced by several processing units and hardware controlled by the STISIM software, is an actual, red Volkswagen (VW) Bug. A picture of the VW Bug and the driving simulator is shown in Figure 4.2, MIT Age Lab Driving Simulator, below.

Figure 4.2 – MIT Age Lab Driving Simulator

Although several experiments have been carried out in the driving laboratory prior to this project, very little attention had been given to the way in which the STISIM software controls the dynamics of the car. The dynamics of the car refer to: the depression pressures of the acceleration and brake pedals, the steering wheel friction coefficient and torque gain relative to the simulated position on the road (over-steering/ under-steering), the vehicle's acceleration and deceleration rate in the simulated environment, the speed instability coefficient, and the simulated amount of air-drag on the vehicle (if the accelerator is no longer depressed, the vehicle would come to a stop eventually due to air drag). After reading many driver reviews about the handling characteristics of a VW Bug, a configuration file to control the dynamics of the car was created in accordance with the driver reviews. This file was tested by driving the vehicle numerous times through a simple simulation and subjectively evaluating the configuration. It was changed numerous times until the authors were satisfied that the configuration file created closely resembled the actual driving characteristics of a bug as reviewed by drivers.

4.4.2 Description of Experiment Software

Based on the experiment design described in Section 4.3, the permutated eight test segments were programmed in Microsoft Excel. By using the pre-defined SDL coding scheme outlined in STISIM, the authors were able to program a simulated, but realistic, driving environment. The simulated environment contained: a straight and level, 2 lane, blacktop roadway; green grass and sporadic trees besides the roadway; mountains in the horizon; and a few clouds in the sky. The STISIM software defined the obstacles used in this simulation, a pedestrian crossing the street and a vehicle stopped in the road, to "pop-up" at a specified distance from the driver. To make the simulation more realistic, a light fog was programmed into the simulated environment that made the "pop-up" of the obstacle less noticeable. The posted speed limit was 55 mph.

Since the coding for STISIM is very high-level, only a few parameters are needed to define an event. For example, to define the pedestrian event, only 7 simple parameters are need. Please refer to Pedestrian event line of code described in Figure 4.3, Example of SDL.

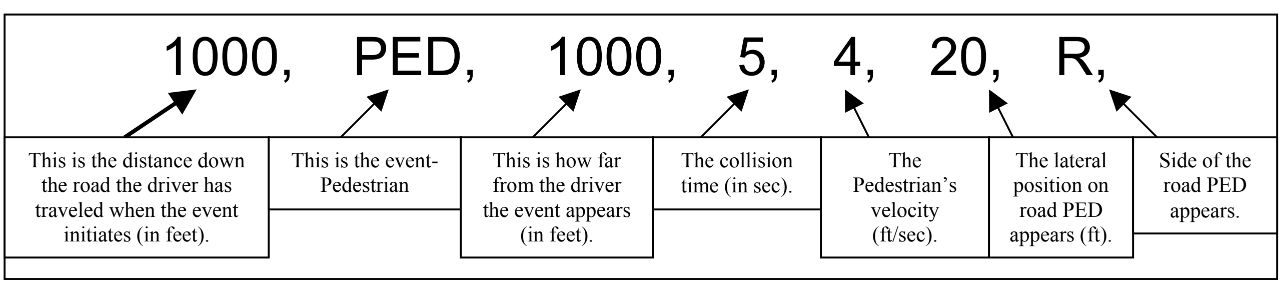


Figure 4.3 – Example of SDL

All coded events are relative to the distance down the road the vehicle has traveled. (This is the first parameter in Figure 4.3.) Using the random function in

Microsoft excel, one of the eight obstacles would "pop-up" at random every 30 to 45 seconds. The simulation was also programmed to begin recording the driver's performance at the beginning of the test segment. These recorded performance parameters are described in further detail in section 4.6, Data Collection.

After completing the SDL programming in Microsoft Excel, it had to be compiled with Visual Basic Editor. The output file from Visual Basic Editor was loaded into STISIM, where the software would load the simulation and then display the graphics on the large screen.

4.5 Subject Testing

A few weeks prior to testing, an email was sent to many graduate and undergraduate students at MIT asking them to voluntarily participate in this experiment. An online web calendar was set up so that subjects could choose a 30 minute time slot that was convenient for them, and at the same timed allowed the authors to easily view the subjects name, time slot, and email address (to send subjects reminders). Testing took place October 24-30, 2003, in the MIT Age Lab Driving Simulator. There were 35 subjects that came to the Age Lab to drive the test segment.

When a subject arrived, he/she was given a pre-test questionnaire to fill out (Please see Appendix E – Pre-Test Questionnaire.), and an informed consent form to sign (Please see Appendix F – Informed Consent Form.). After completing these forms, the driver was escorted to the VW Bug and was shown by the authors how to adjust the seat, steering wheel, and mirrors (although they would not be used). The subject was then given a 6-8 minute, training segment (courtesy of Bryan Reimer and the Age Lab) to help familiarize himself/herself with the handling characteristics of the vehicle. After the training segment, the driver was asked if he/she had any questions or comments and was given brief and varying instructions about how to drive the test segment. Then the actual test segment was loaded onto the big screen. The authors took notes of the drivers' behavior as he/she drove the test course. For example, comments like, "Driver did not stop for 2nd vehicle event," or "Driver was driving 20 mph over the speed limit," were recorded. These comments, in addition to examination of the raw data, were the basis for disregarding 3 subject's data. In addition, 5 more subjects' data were disregarded or not taken due to equipment malfunction and/or simulator sickness. As a thank you for participating, the subject was offered food and drink when leaving.

4.6 Data Collection

For each scenario run, the Driving Simulator's main computer produced a data file. Prior to running the simulation testing, the computer had to be programmed to record the necessary information in the output data file. (Please refer to See Section 4.4.2.) The simulator computer recorded at a frequency of 60 Hz, or every 0.04 seconds. The output file contained the distance the vehicle traveled down the road, the distances at which the events (vehicle or pedestrian) first became visible ("popped-up"), and also recorded all instances of brake depression by the driver.

From this output file the necessary extracted measurement was the driver's braking response distance for each of the eight events. In order to get that measurement, the instant of braking in response to an event had to be determined by analyzing the brake depression data to find when the driver first began depressing the brake, referred to as the braking instant. The braking instant corresponds to a distance traveled down the road by the driver, and this distance is compared to the distance of the event to get the braking response distance. (Refer to Figure 4.1 – Definition of Braking Response Distance.)

5.0 Results

5.1 Results from Reliability and Confidence Test

After reducing the data and extracting out every driver's braking response distance to all eight events, the driver's braking responses were compared. A driver's event response distance was compared for each distance increase of 200 feet: 400 vs. 600, 600 vs. 800 and 800 vs. 1000 feet. For example, Driver 1's vehicle braking response distance at 400feet, was compared to his/her vehicle braking response distance at 600feet. If his/her braking response distance increased by 10% with the addition of 200 feet, his/her result was considered a "success." On the contrary, if Driver 1's pedestrian braking response distance at 600feet, was decreased with the addition of 200feet, or did not increase by at least 10% when compared to his/her pedestrian braking response distance at 400feet, his/her result was considered a "failure." This trend is depicted in Figure 5.1 - % Increase or Decrease for 400 vs. 600feet.

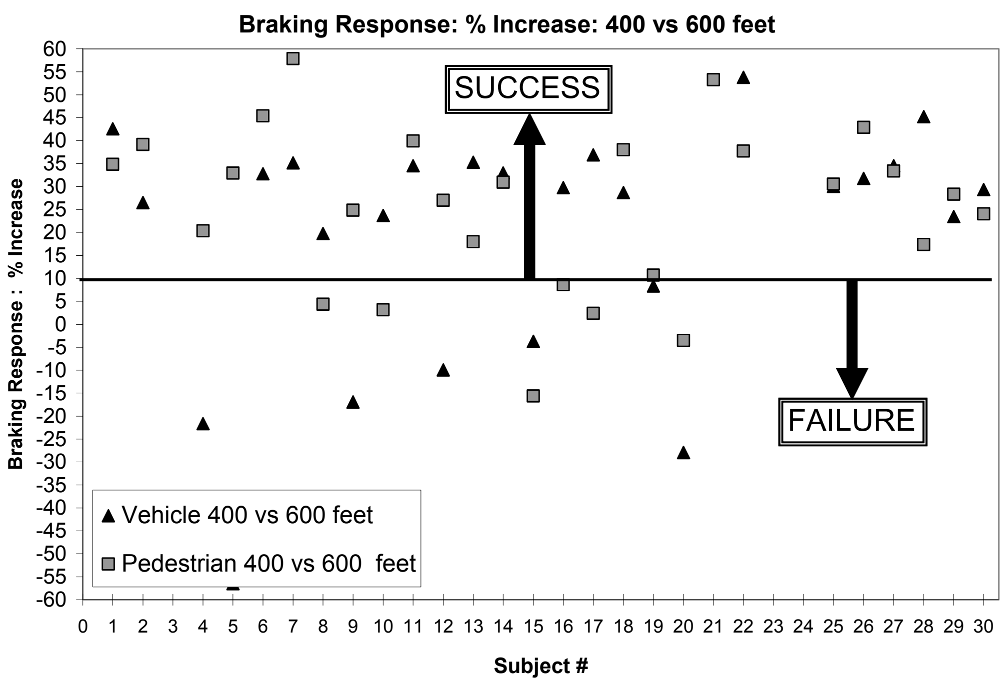


Figure 5.1 - % Increase or Decrease for 400 vs. 600 feet

This same type of analysis was performed on all usable drivers' data for the three distance comparisons. Please refer to Appendix D, % Increase or Decrease Trends, for detailed graphical depiction of all comparisons. Using the above stated criteria for "success" (a 10% increase in braking response distance if driver has an additional 200 feet of vision) and "failure" (an increase of less than 10% in braking response distance, or a decrease in response distance with an increase of 200 feet of vision), the drivers' data was categorized and a count was kept. Based on the size of the sample space and the number of "failures," Larson's Binomial Distribution Nomograph, shown in Appendix G, could be used to evaluate the reliability of the results and the confidence in that reliability. See Table 5.1 for the results that were found for 90% confidence and 75% reliability by using the Larson Binomial Distribution Nomograph. The sample size for all comparisons was 54.

Table 5.1 – Confidence and Reliability Results

Distance:	# Success's	# Failure's	If 90 % Confident, Reliability is:	If 75 % Reliable, Confidence is:
400 vs. 600ft	41	13	68%	56%
600 vs. 800ft	39	15	65%	36%
800 vs. 1000ft	24	30	< 50% (off scale)	0%

There are a few important things to note. First, reliability and confidence level are a trade-off, and are directly proportional to the sample size and indirectly proportional to the number of failures. Also, as will be discussed further in Section 6.1, the results stipulated in Table 5.1 do not meet the success criterion outlined for this project.

5.2 Results from Pedestrian vs. Vehicle Comparison

Before continuing to determine if the addition of 200 feet in long range vision affects a driver's braking response distance for the specified distance intervals, it was necessary to investigate whether the two events, the pedestrian and the vehicle, elicited a different response from the drivers. The distribution of these results is shown in Figure 5.2 – Braking Response to Pedestrian and Vehicle Events.

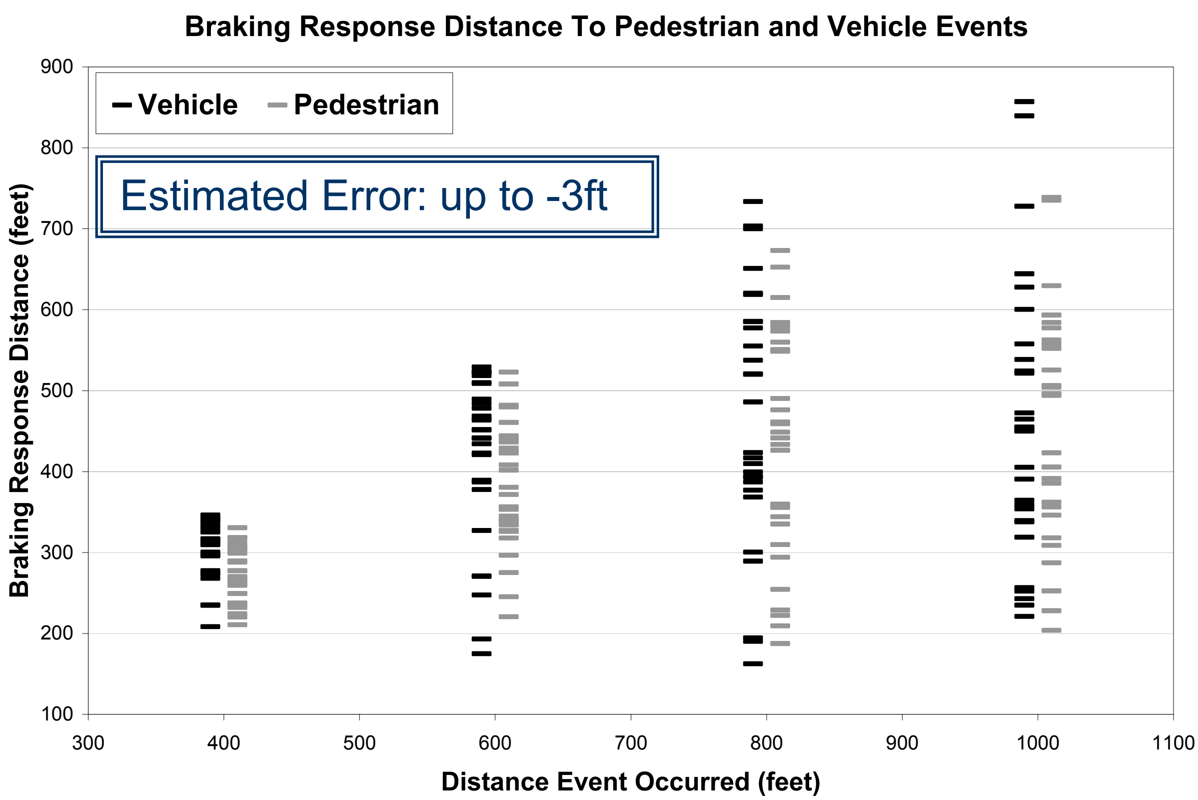


Figure 5.2 – Braking Response Distance to Pedestrian and Vehicle Events

After collecting this data, the mean and variance for each event distribution was calculated for each event distance. In addition, four paired t-tests were performed to determine if the responses obtained for the pedestrian and vehicle events were different. A paired t-test compares each subject's data for each event response at the given distance based on the mean and variance of the overall distribution. If these data distributions overlap significantly, then the data is essentially the same. If the data overlaps just slightly, or not at all, then the results obtained are different. A significance level of 5% (0.05) was used. The lesser the results are than 5%, the more significant is the difference. Please refer to Table 5.2, Pedestrian vs. Vehicle Distribution and Significance Summary, for a summary of the calculations.

Table 5.2 - Pedestrian vs. Vehicle Distribution and Significance Summary

	400 Feet	600 Feet	800 Feet	1000 Feet
Pedestrian	Mean:272 SD:33	Mean:380 SD:78	Mean:434 SD:144	Mean:476 SD:138
Vehicle	Mean:306 SD:36	Mean:418 SD:105	Mean:474 SD:157	Mean:465 SD:171
Significance	7.22E-04	0.0236	0.165511	0.844604

It is important to note that for 400, 600, and 800 feet, the pedestrian and vehicle events elicited a different response from the driver. As will be discussed in further detail in Section 6.2, this means that data analysis for Distance Response Comparison (Section 5.3) was carried out separately for the two different events.

5.3 Significance Results from Distance Response Comparison

After determining that it is necessary to carry out the analysis of the braking response distances for the different events separately, paired t-test were performed on the subjects' data for comparison between consecutive 200 foot increments. The results of those t-tests are shown in Table 5.3 – Distance Response Comparison Results. Like the t-tests performed for the vehicle and the pedestrian comparison, a significance level of 5% was used.

Table 5.3 – Distance Response Comparison Results

Distance:	Event:	T-test P value:	Significance?
400 vs. 600ft	Pedestrian	4.93E-07	Different
	Vehicle	8.30E-06	Different
600 vs. 800ft	Pedestrian	0.02897	Different
	Vehicle	0.01393	Different
800 vs. 1000ft	Pedestrian	0.16677	Same
	Vehicle	0.77248	Same

The result of these comparisons is that drivers respond differently to events when they appear 200 feet further in the distance for 400 vs. 600, and 600 vs. 800 feet. Drivers do not respond differently when these events appear further in the distance than 800 feet. The significance of these results is discussed further in Section 6.3.

6.0 Discussion

6.1 Discussion of Results from Reliability and Confidence Test

6.1.1 Analysis of Results

The results from the Reliability and Confidence test show that there were too many failures to achieve the level of reliability and confidence in the results that was required by the success criterion. An interesting trend, however, is that the reliability and confidence in the data increases as the distance to the event decreases. This indicates that for very close distances, such as 400 and 600 feet, that seeing an object sooner has a large effect on the performance of a driver. Likewise, as the problem gets pushed further away from the driver, increasing the range at which the driver can see and contemplate the problem does not have a significant effect on how the driver will respond to the event. This suggests that research should be focused on improving mid to close range vision, and that long ranges vision reaches a point at which seeing farther does not improve performance.

6.1.2 Comparison to Expected Results

The reason that the data did not achieve the confidence and reliability quoted in the success criterion is primarily due to the fact that the experiment was not large enough. With a total of 27 sets of usable data, only 6 "failures" were allowed in order to attain the success criterion confidence and reliability. If the experiment were conducted again, a larger subject pool should be used in order to improve the reliability and confidence of the results.

6.1.3 Discussion of Large Errors

There were no large measurable errors associated with this experiment. The single measurable error comes from the fact that the simulator computer only records every .04 seconds, which corresponds to 3 feet traveling at 55 miles per hour (the average speed of the drivers). When deciding when the brake was depressed it is possible that the brake depression actually occurred sometime before it showed up on data file. So there is a max error of negative 3 feet in determining the braking response distance.

There were other immeasurable sources of error. One is the discrepancy between simulator driving and real world driving, which makes the direct comparison of the experiment results to real world driving conditions more difficult and error prone. Also, there is the discrepancy between information briefed to the subjects. Some subjects had to be told to obey the speed limit because they were speeding and after that may have reacted more conservatively. Also, some subjects were familiar with the authors conducting this experiment, and that could have caused them to drive differently than they would otherwise.

6.1.4 *Relation of Results*

Since there was not a confidence level of 90% in the data and the obtained result were not reliable 75% of the time, the success criterion were not met in this study. However, the results did indicate a general trend that is consistent with the hypothesis. There is an increasingly significant difference in driver braking response time with an increase in vision range when the event is in the mid to close range from the driver (400-600 feet).

6.2 Discussion of Results from Pedestrian vs. Vehicle Comparison

6.2.1 *Analysis of Results*

The important result from the pedestrian vs. vehicle significance testing is that the braking response data from the two different events could not be analyzed together. In general, the pedestrian event behaved in a more predictable way and the variance of the pedestrian results was less than that of the vehicle event. If the experiment were to be repeated, it is suggested that an event such as the pedestrian were used several times instead of also incorporating the vehicle event.

6.2.2 *Comparison to Expected Results*

The reason that results to the vehicle event did not behave like that of the pedestrian event is that vehicle function was poorly designed by STISIM. The vehicle was parked in the roadway ahead of the driver. The way the function was intended to work was that the driver would brake in response viewing the parked car, then drive closer to the car or attempt to pass it, and the vehicle would then take off. However, on their first encounter with the vehicle event, most drivers broke in response to viewing the car, and then did nothing, expecting the car to move. The drivers then had to be instructed to pull closer to the car or try to pass it – giving away how the function works. The reason for this characteristic was that the simulator SDL software defined the vehicle take-off point as a function of the closing time between the driver and the parked car. This meant that as the driver accelerated toward the vehicle it would take off (whether the driver had broken or not). Some subjects figured this behavior out and did not respond to the vehicle the same way that they would if it were really parked in the roadway ahead of them. Some even accelerated towards the parked vehicle, never attempting to slow down or stop. This function worked so poorly, in fact, as shown by the compelling experiment results, that the Age Lab recently spent money and man-hours rewriting this aspect of the software.

6.2.3 Discussion of Large Errors

There no real sources of error present in this test, other than the fact that the vehicle event did not behave as expected. Also, the negative three feet of braking distance is still a possible source of error (See section 6.1.3 for further discussion.)

6.2.4 Relation of Results

This result affected the evaluation of the hypothesis in that it dictated the pedestrian and vehicle events be treated separately in the analysis.

6.3 Discussion of Significance Results from Distance Response Comparison

6.3.1 *Analysis of Results*

Analysis procedure after the pedestrian and vehicle events were separated, (See 6.2 for discussion on why they were separated), was to run paired T-Tests on the different distance pairs as follows: 400 vs. 600 feet, 600 vs. 800 feet and 800 vs. 1000 feet, to see if the driver's response distance was statistically different with 200 feet of increased vision capabilities. The significance tests indicated that the drivers' responses were different for events at 400 and 600 feet, and also for events at 600 and 800 feet. The response was not statistically different between 800 and 1000 feet. This indicates is that there is a point where adding more distance to the driver's vision capability no longer increases the braking response distance, and that that point is somewhere between 800 and 1000 feet.

6.3.2 *Comparison to Expected Results*

Not much previous work has been done trying to characterize how long-range vision impacts braking response distance; however, it was hypothesized that increasing the long-range vision does increase the driver's response distance, meaning that the driver responds more conservatively in situations where he or she has more time to react. It is interesting to note here that only on very few occasions did collisions occur, which means that drivers were braking before they needed to when given the option to respond earlier.

In all cases the minimum distance at which people broke to avoid collision was approximately the same, and that distance was around 200 feet. What this says is that even with the increased visual range, some drivers still broke at the last possible minute, but that those drivers still recognized the same distance (200 feet before the object) to be the last opportunity to brake.

6.3.3 *Discussion of Large Errors*

As was stated in the above sections (See section 6.1.3), the only measured error is still negative three feet.

6.3.4 Relation of Results

These results support the basic idea of the hypothesis. The braking response distance in general increased with increase in long-range vision. The significance of the results, however, decreased as the long-range vision increased, until it reached a point past which the breaking response was unchanged.

7.0 Summary and Conclusion

7.1 Summary of Findings

This experiment found that there is a statistical difference in a driver's braking response to objects that he/she can see 400 feet in the distance as opposed to 600 feet, and at 600 feet as opposed to 800 feet. For this range, the increase in long-range vision of 200 feet corresponds to an increase in braking response distance. However, the confidence and reliability measures obtained in the data for this experiment were not as predicted in the success criterion (See Table 5.1). The noted trend for the obtained confidence level and reliability in this project's results is that as the distance to the object increases, the reliability and confidence that the braking response will also increase, declines. The experiment also found that there is no statistical difference in a driver's braking response distance for objects that they can see 800 feet in the distance as opposed to 1000 feet. This suggests that there is a point at which adding more to a driver's long-range vision capabilities no longer affects that driver's braking response distance, and that threshold occurs somewhere between 800 and 1000 feet.

7.2 Assessment of Hypothesis

The findings of this experiment is that an additional 200 feet in a driver's long-range vision increases the driver's braking response distance by 10% for distances up to 800 feet; however, not to the reliability and level of confidence stipulated in the success criterion for this project. (See Sections 5.1, and 6.1.) The project results, therefore suggest that this hypothesis may be true. However the experiment carried out by the authors did not include enough subjects to attain the reliability and confidence level in the results that are stipulated in the success criterion. Future work can be done to assess this hypothesis further and more accurately.

7.3 Suggestions for Future Work

This experiment laid the groundwork for a larger study into the effects of degrading vision on driver performance. In particular, MIT's Age Lab is interested in expanding the study to test older drivers and see how they respond. For future studies, it is recommended that the pedestrian type event be used instead of the vehicle event, or to use a modified vehicle event that behaves more predictably and forces the driver to brake. Additionally, a larger subject pool is needed in order to have a higher reliability and confidence in the results. Finally, a smaller distance increment could be used in order to better evaluate at which distance an increase in long-range vision no longer affects a driver's braking response. This experiment found that threshold distance to be between 800 and 1000 feet.

8.0 References

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9.0 Acknowledgements

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- The MIT Age Lab and Dr. Coughlin – for allowing use of their facilities to carry out this experiment.

Appendix A – Collected Raw Data

Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
1	1	M	P	400	265.78
1	1	M	V	800	485.98
1	1	M	P	600	408.07
1	1	M	P	800	461.17
1	1	M	P	1000	423.05
1	1	M	V	400	300.48
1	1	M	V	600	523.34
1	1	M	V	1000	337.75
2	4	F	V	600	465.11
2	4	F	P	400	270.07
2	4	F	V	800	585.52
2	4	F	V	1000	472.46
2	4	F	V	400	341.91
2	4	F	P	800	579.02
2	4	F	P	1000	577.37
2	4	F	P	600	444.06
3	3	M	P	600	334.05
3	3	M	V	1000	256.61
3	3	M	P	800	355.67
3	3	M	P	1000	346.1
3	3	M	P	400	247.19
3	3	M	V	600	451.79
3	3	M	V	800	300.49
3	3	M	V	400	
4	2	F	V	400	234.66
4	2	F	P	1000	308.76
4	2	F	V	600	192.94
4	2	F	V	800	162.47
4	2	F	V	1000	221.09
4	2	F	P	600	326.17
4	2	F	P	800	228.73
4	2	F	P	400	259.76
5	8	F	V	1000	644.46
5	8	F	P	800	433.42
5	8	F	V	400	273.75
5	8	F	V	600	174.92
5	8	F	V	800	194.31
5	8	F	P	400	249.26
5	8	F	P	600	371.68
5	8	F	P	1000	495.16

Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
6	7	M	P	1000	318.17
6	7	M	V	600	484.09
6	7	M	P	400	277.49
6	7	M	P	600	508
6	7	M	P	800	559.96
6	7	M	V	1000	557.59
6	7	M	V	400	325.31
6	7	M	V	800	585.14
7	4	F	V	600	529.3
7	4	F	P	400	220.25
7	4	F	V	800	733.59
7	4	F	V	1000	857.12
7	4	F	V	400	343.12
7	4	F	P	800	673.16
7	4	F	P	1000	735.16
7	4	F	P	600	522.66
8	6	m	V	800	368.4
8	6	m	P	600	220.41
8	6	m	V	1000	454.97
8	6	m	V	400	339.29
8	6	m	V	600	422.83
8	6	m	P	1000	496.13
8	6	m	P	400	210.76
8	6	m	P	800	344.17
9	2	m	V	400	316.79
9	2	m	P	1000	252.35
9	2	m	V	600	270.96
9	2	m	V	800	392.96
9	2	m	V	1000	524.1
9	2	m	P	600	344.97
9	2	m	P	800	448.57
9	2	m	P	400	259.32
10	7	m	P	1000	203.63
10	7	m	V	600	389.14
10	7	m	P	400	237.55
10	7	m	P	600	245.31
10	7	m	P	800	490.14
10	7	m	V	1000	252.1
10	7	m	V	400	296.97
10	7	m	V	800	387.05

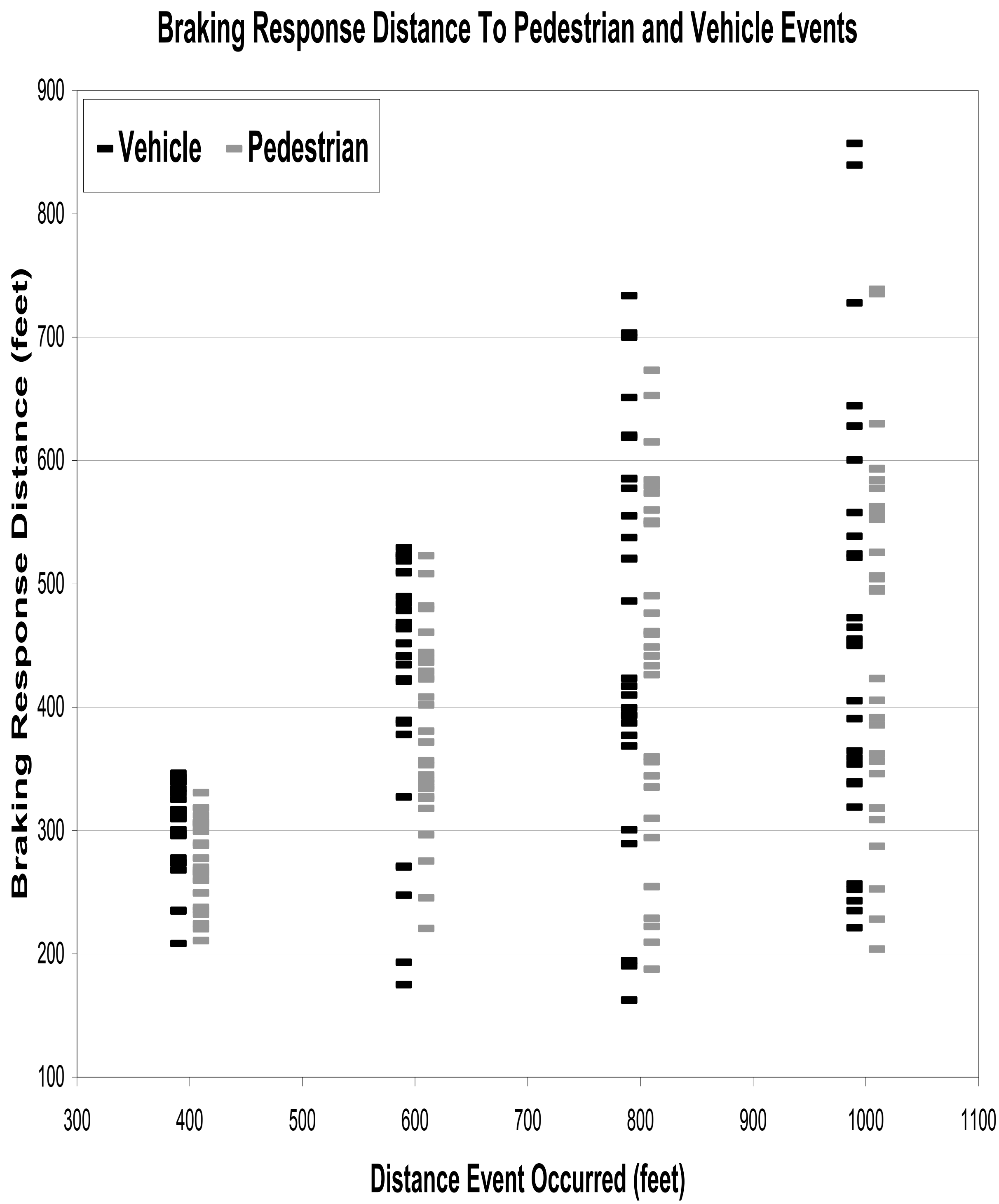
Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
11	8	m	V	1000	538.53
11	8	m	P	800	294.06
11	8	m	V	400	339.43
11	8	m	V	600	518.63
11	8	m	V	800	520.72
11	8	m	P	400	289.56
11	8	m	P	600	481.91
11	8	m	P	1000	525.55
12	4	m	V	600	270.35
12	4	m	P	400	231.99
12	4	m	V	800	520.08
12	4	m	V	1000	339.45
12	4	m	V	400	297.32
12	4	m	P	800	550.91
12	4	m	P	1000	562.52
12	4	m	P	600	317.8
13	3	m	P	600	380.56
13	3	m	V	1000	839.52
13	3	m	P	800	615.04
13	3	m	P	1000	738.81
13	3	m	P	400	312.13
13	3	m	V	600	478.38
13	3	m	V	800	703.32
13	3	m	V	400	309.46
14	1	f	P	400	235.36
14	1	f	V	800	417.08
14	1	f	P	600	340.86
14	1	f	P	800	426.18
14	1	f	P	1000	391.31
14	1	f	V	400	314.1
14	1	f	V	600	468.49
14	1	f	V	1000	450.38
15	5	m	P	800	254.34
15	5	m	V	400	339.26
15	5	m	P	1000	362.17
15	5	m	P	400	318.17
15	5	m	P	600	275.16
15	5	m	V	800	289.38
15	5	m	V	1000	243
15	5	m	V	600	327.12

Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
16	5	m	P	800	222.08
16	5	m	V	400	295.67
16	5	m	P	1000	405.55
16	5	m	P	400	299.17
16	5	m	P	600	327.32
16	5	m	V	800	409.86
16	5	m	V	1000	464.64
16	5	m	V	600	420.89
17	6	m	V	800	376.9
17	6	m	P	600	338.89
17	6	m	V	1000	390.52
17	6	m	V	400	330.42
17	6	m	V	600	523.85
17	6	m	P	1000	504.26
17	6	m	P	400	330.71
17	6	m	P	800	441.44
18	5	f	V	600	434.33
18	5	f	P	400	265.85
18	5	f	V	800	555.04
18	5	f	V	1000	364.5
18	5	f	V	400	309.76
18	5	f	P	800	359.77
18	5	f	P	1000	593.21
18	5	f	P	600	428.97
19	8	m	V	1000	405.36
19	8	m	P	800	459.06
19	8	m	V	400	346.28
19	8	m	V	600	377.83
19	8	m	V	800	393.84
19	8	m	P	400	318.34
19	8	m	P	600	356.49
19	8	m	P	1000	552.23
20	6	f	V	800	190.02
20	6	f	P	600	296.48
20	6	f	V	1000	234.95
20	6	f	V	400	316.7
20	6	f	V	600	247.53
20	6	f	P	1000	287.19
20	6	f	P	400	306.94
20	6	f	P	800	187.57

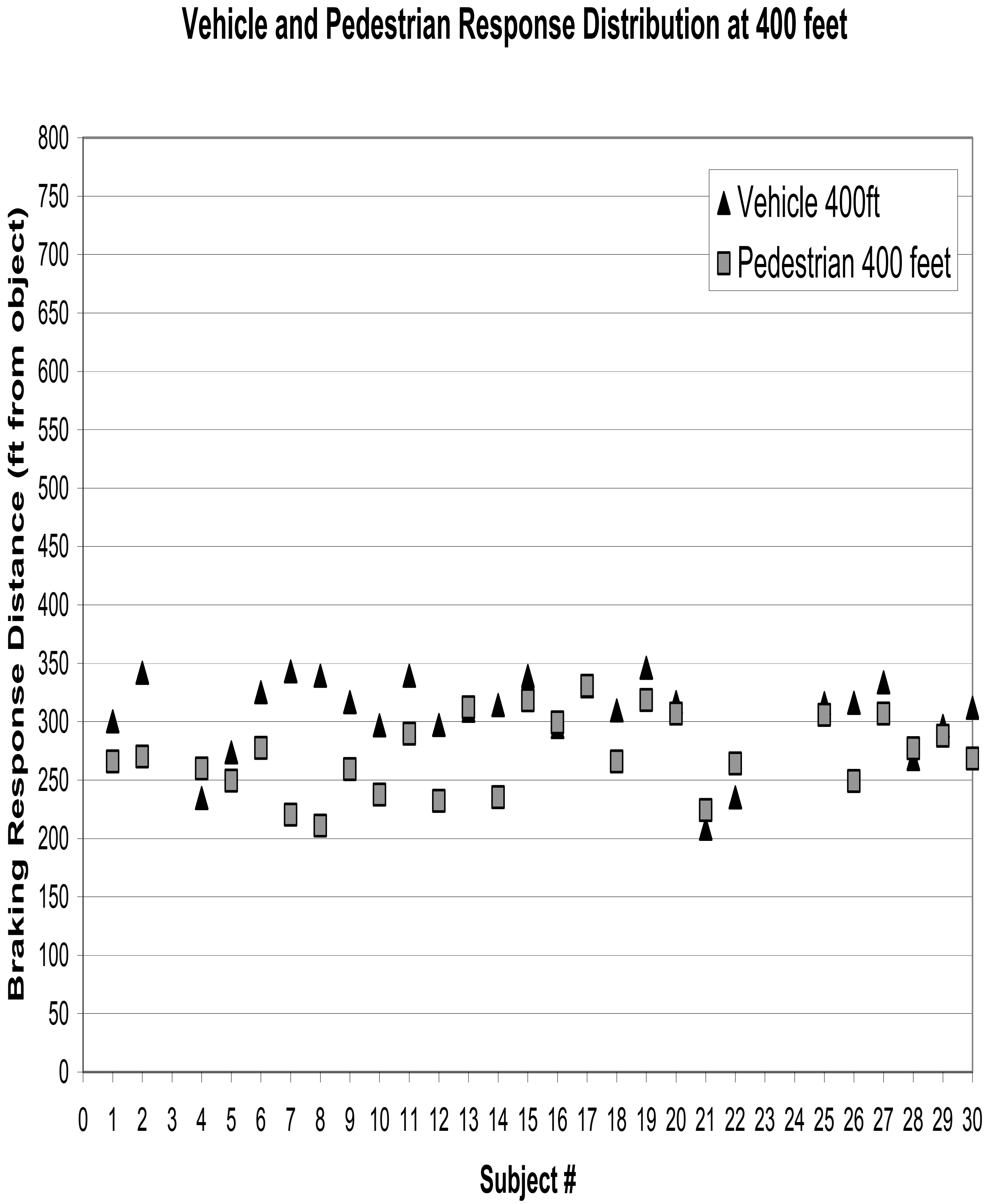
Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
21	1	m	P	400	224.28
21	1	m	V	800	620.41
21	1	m	P	600	479.91
21	1	m	P	800	584.07
21	1	m	P	1000	494.03
21	1	m	V	400	208.27
21	1	m	V	600	522.09
21	1	m	V	1000	600.37
22	3	f	P	600	424.29
22	3	f	V	1000	727.71
22	3	f	P	800	476.03
22	3	f	P	1000	557.83
22	3	f	P	400	264.14
22	3	f	V	600	508.88
22	3	f	V	800	423.31
22	3	f	V	400	235.24
23	5	f	P	800	247.15
23	5	f	V	400	273.65
23	5	f	P	1000	570.72
23	5	f	P	400	302.57
23	5	f	P	600	478.6
23	5	f	V	800	
23	5	f	V	1000	
23	5	f	V	600	
24	2	m	V	400	277.5
24	2	m	P	1000	228.08
24	2	m	V	600	441.07
24	2	m	V	800	401.24
24	2	m	V	1000	454.52
24	2	m	P	600	422.93
24	2	m	P	800	
24	2	m	P	400	305.2
25	7	m	P	1000	356.07
25	7	m	V	600	451.48
25	7	m	P	400	305.75
25	7	m	P	600	440.21
25	7	m	P	800	548.77
25	7	m	V	1000	449.99
25	7	m	V	400	315.82
25	7	m	V	800	618.83

Subject #	Scenario #	Sex	Event Type (Pedestrian/ Vehicle)	Distance Event Popped Up(ft)	Braking Response-(Distance from Object driver began to brake)(ft)
26	1	m	P	400	249.19
26	1	m	V	800	650.99
26	1	m	P	600	436.38
26	1	m	P	800	573.47
26	1	m	P	1000	584.03
26	1	m	V	400	316.26
26	1	m	V	600	463.48
26	1	m	V	1000	521.57
27	2	m	V	400	333.69
27	2	m	P	1000	629.61
27	2	m	V	600	509.65
27	2	m	V	800	577.35
27	2	m	V	1000	627.87
27	2	m	P	600	460.71
27	2	m	P	800	652.59
27	2	m	P	400	306.78
28	3	m	P	600	335.4
28	3	m	V	1000	358.83
28	3	m	P	800	335.13
28	3	m	P	1000	506.31
28	3	m	P	400	277.15
28	3	m	V	600	489.35
28	3	m	V	800	537.46
28	3	m	V	400	268.02
29	5	m	P	800	309.67
29	5	m	V	400	296.4
29	5	m	P	1000	385.62
29	5	m	P	400	287.93
29	5	m	P	600	401.67
29	5	m	V	800	399.28
29	5	m	V	1000	318.74
29	5	m	V	600	387.23
30	8	m	V	1000	353.87
30	8	m	P	800	209.17
30	8	m	V	400	311.83
30	8	m	V	600	441.49
30	8	m	V	800	699.98
30	8	m	P	400	268.25
30	8	m	P	600	353.12
30	8	m	P	1000	593.54

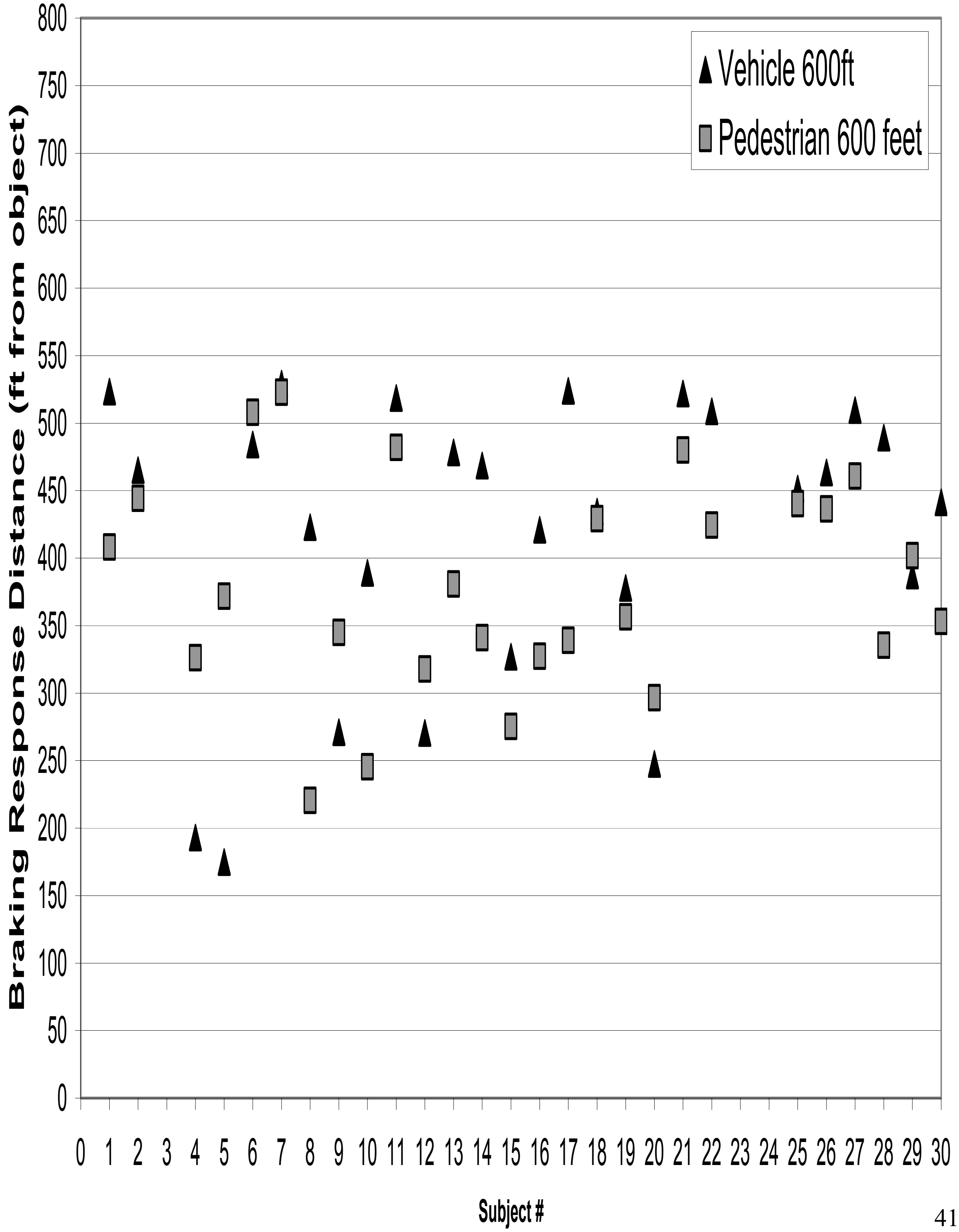
Appendix B – Pedestrian vs. Vehicle Distribution

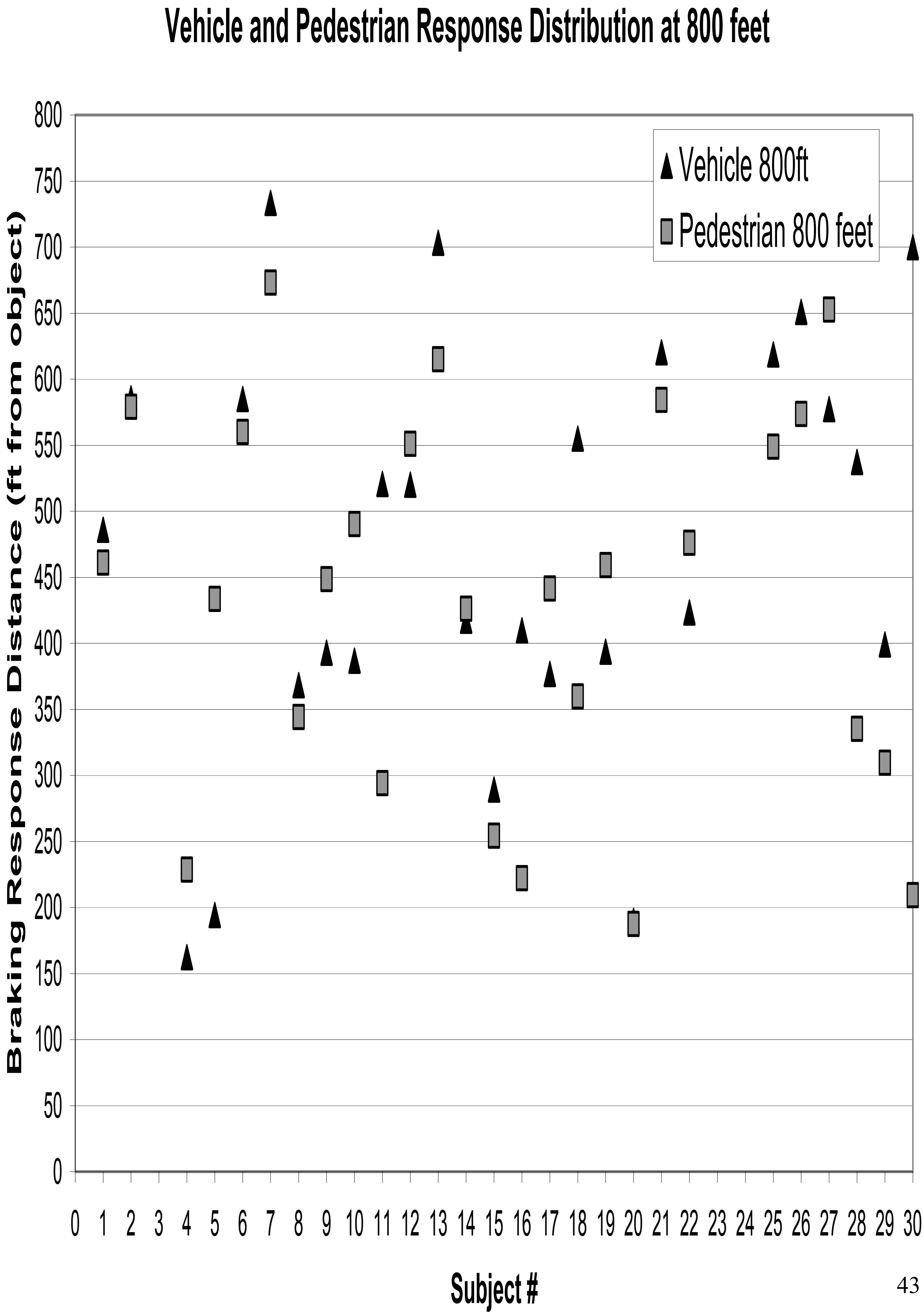


Appendix C – Data Distribution at 400, 600, 800, 1000 Feet

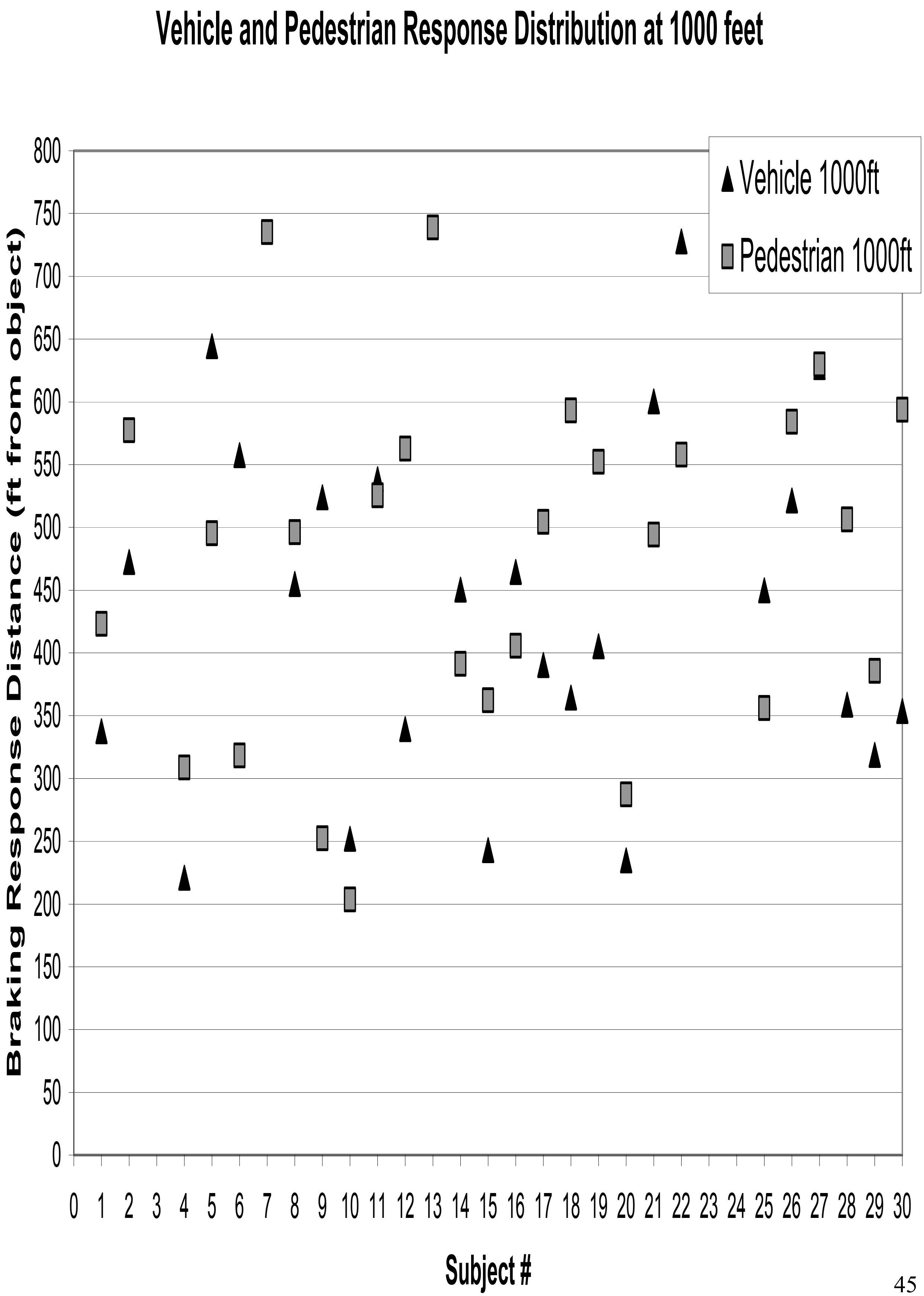


Vehicle and Pedestrian Response Distribution at 600 feet



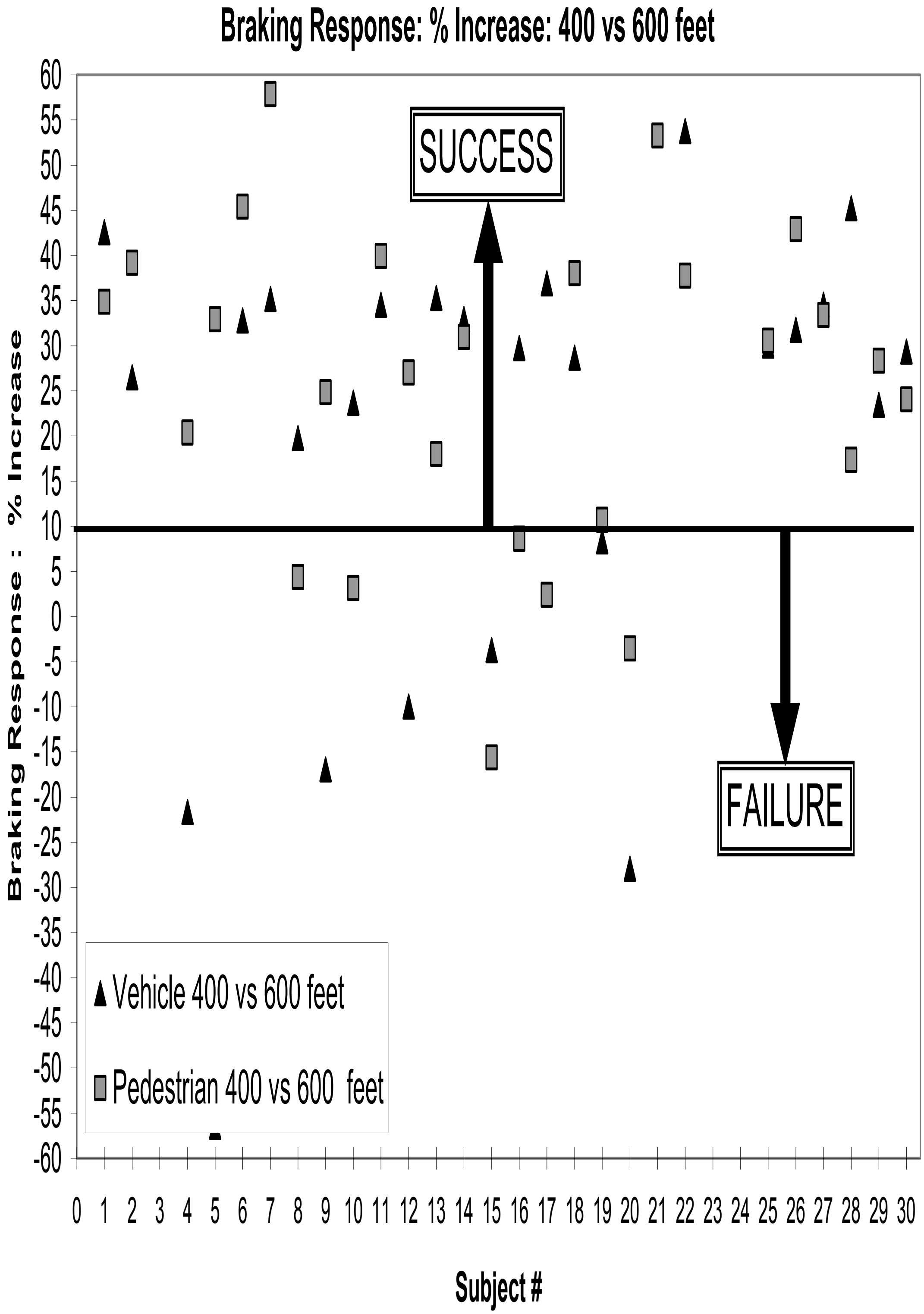


Vehicle and Pedestrian Response Distribution at 800 feet
Vehicle 800ft
Pedestrian 800 feet
Braking Response Distance (ft from object)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Subject #

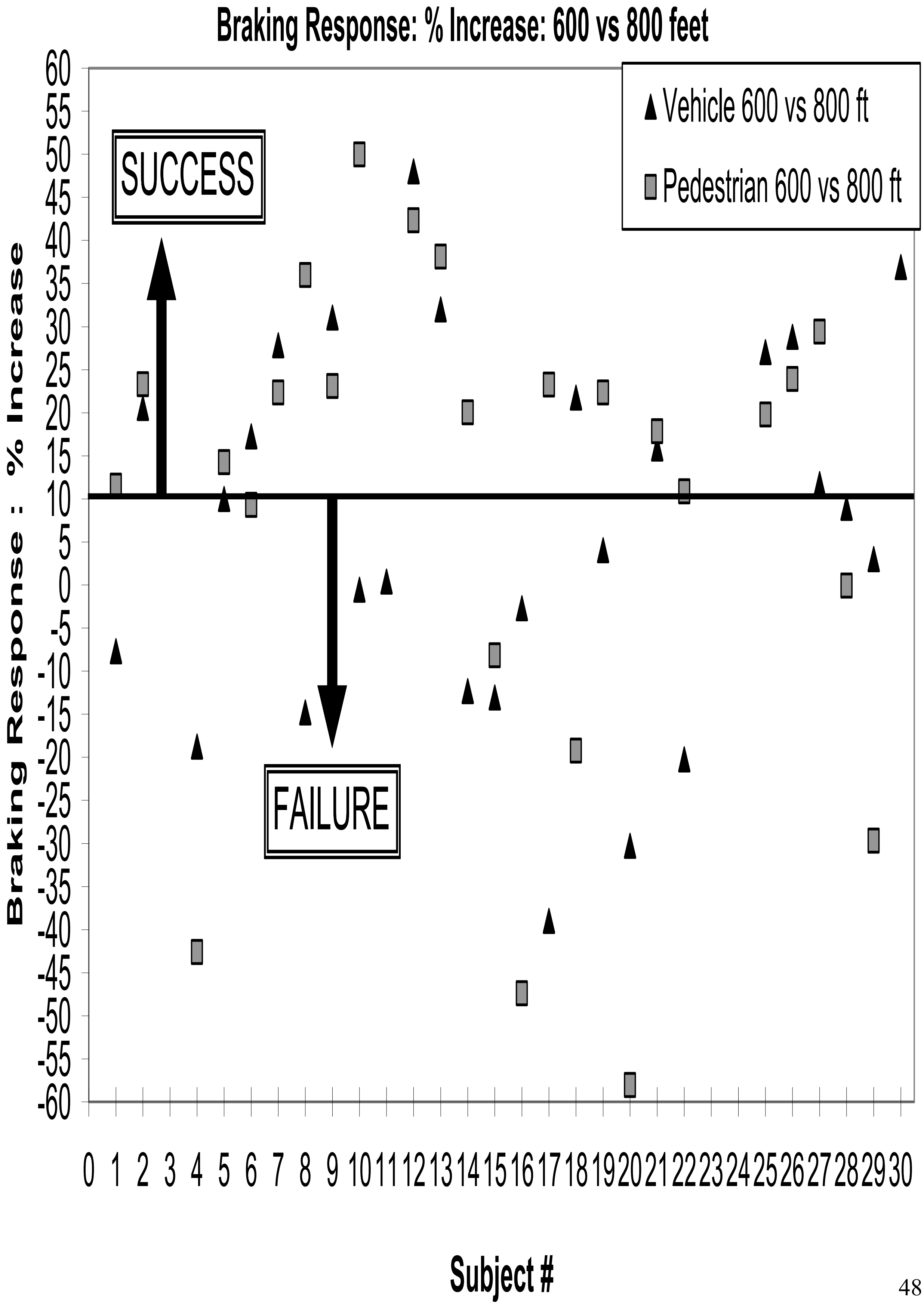


Vehicle and Pedestrian Response Distribution at 1000 feet
Vehicle 1000ft
Pedestrian 1000ft
Braking Response Distance (ft from object)
Subject #
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

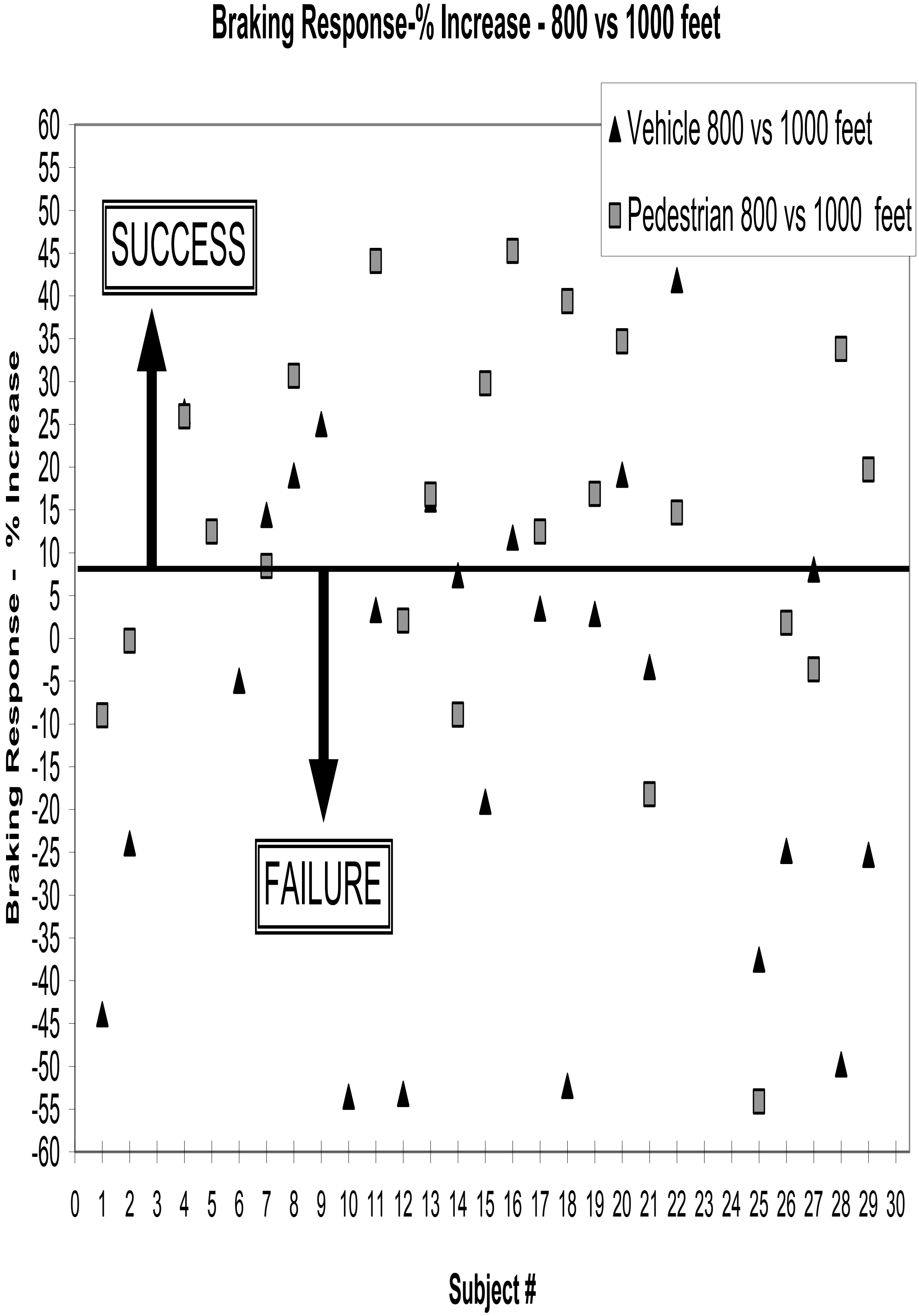
Appendix D - % Increase or Decrease Trends



Braking Response: % Increase: 400 vs 600 feet
SUCCESS
FAILURE
Braking Response : % Increase
Subject #
Vehicle 400 vs 600 feet
Pedestrian 400 vs 600 feet
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30



Braking Response: % Increase: 600 vs 800 feet
Vehicle 600 vs 800 ft
Pedestrian 600 vs 800 ft
SUCCESS
FAILURE
Braking Response : % Increase
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Subject #


Braking Response-% Increase - 800 vs 1000 feet
Vehicle 800 vs 1000 feet
Pedestrian 800 vs 1000 feet
SUCCESS
FAILURE
Braking Response - % Increase
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Subject #

Appendix E – Pre-Test Questionnaire

16.622 Driving Simulator Experiment: Subject Form

Subject Pre-Test Questionnaire

1. Name: ________________________
2. Sex: M F
3. Age:_______
4. MIT Affiliation/Course: ___________
5. Years of Driver Experience: ________
6. Vision (with contacts and/or glasses) at time of experiment: ________

Test Information

1. Set # Completed:________
2. Trainer Completion Time: Segment 1______ Segment 2______Segment 3______
3. Difficulties with trainer:____

   ____
4. Time to Complete Test Segment: __________
5. Notes on Driver Behavior/Performance: ________________________________

   ____

   ____

   ____

Subject Post-Test Comments

____